

Transverse Λ Polarization at LHC

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Transverse polarization of Λ hyperons produced in pp and pPb collisions is discussed. A factorized description in the intermediate to high p_T region is considered that involves transverse momentum and spin dependence in the fragmentation process. Consequences and suggestions for investigations at LHC are pointed out for the process $p + p \rightarrow \Lambda^\uparrow + \text{jets} + X$ at midrapidity and $p + p/Pb \rightarrow \Lambda^\uparrow + X$ in the forward region.

1 Introduction

It is well-known since the mid-1970's that Λ hyperons produced in unpolarized pp collisions are to a large degree polarized transversely to the production plane. There have been many experimental and theoretical investigations aimed at understanding this striking polarization phenomenon, but no consensus has been reached about its origin. One of the difficulties in interpreting the available (mostly fixed target) data is that they are not or only partially in a region where a factorized description of the cross section is expected to be applicable. High-energy hadron collider data would be very welcome, for instance from RHIC, Tevatron or LHC, but there the capabilities to measure Λ polarization via the self-analyzing parity violating decay $\Lambda \rightarrow p\pi^-$ are typically restricted to the midrapidity region, where protons can be identified, but the degree of transverse polarization P_Λ is expected to be very small. For symmetry reasons $P_\Lambda = 0$ at midrapidity in pp collisions in the center of mass frame. Nevertheless, some interesting Λ polarization studies can be done using the process $p + p \rightarrow \Lambda^\uparrow + \text{jets} + X$, where the Λ and jets can be in the midrapidity region without paying a suppression penalty. It is especially of interest at LHC, where the asymmetry expressions may take a particularly simple form depending on the importance of gluons. Also, transverse Λ polarization measurements at forward rapidities at LHC will be discussed below, as it offers a promising way of extracting the x dependence of the saturation scale. These two suggestions will hopefully enhance the interest in Λ polarization measurements at high energy colliders, at LHC in particular.

2 Transverse Λ polarization in unpolarized collisions

Large asymmetries have been observed in $p + p \rightarrow \Lambda^\uparrow + X$ [2]. The main features of the asymmetry are: $|P_\Lambda|$ grows with x_F and p_T ($\lesssim 1 \text{ GeV}/c$); for $p_T \gtrsim 1 \text{ GeV}/c$ it becomes flat (measured up to $4 \text{ GeV}/c$); no \sqrt{s} dependence has been seen. For a comprehensive review of data cf. Ref. [3]. Many QCD-inspired models have been proposed to explain the transverse Λ polarization data. Most models give qualitative descriptions of the data for $p_T \lesssim 1-2 \text{ GeV}/c$. However, P_Λ stays large at least until the highest measured $p_T \sim 4 \text{ GeV}/c$. For sufficiently large p_T perturbative QCD and collinear factorization should become applicable. Consider for example the $qg \rightarrow qg$ subprocess contribution to the $pp \rightarrow \Lambda X$ cross section in collinear factorization. It is of the form: $\sigma \sim q(x_1) \otimes g(x_2) \otimes \hat{\sigma}_{qg \rightarrow qg} \otimes D_{\Lambda/q}(z)$,

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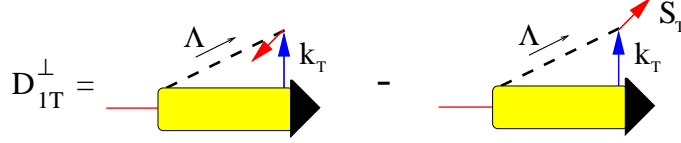


Figure 1: Nonzero D_{1T}^\perp for Λ 's means that the transverse polarization S_T of Λ 's (with momentum $K_\Lambda \approx zq + k_T$) arising from a fragmenting unpolarized quark (with momentum q) is nonzero. It is a k_T -odd, chiral-even TMD fragmentation function.

where $q(x_1)$ is the quark density in proton 1, $g(x_2)$ is the gluon density in proton 2, and $D_{\Lambda/q}(z)$ is the Λ fragmentation function (FF). In a similar way the transverse polarization should be of the form: $P_\Lambda \sim q(x_1) \otimes g(x_2) \otimes \hat{\sigma}_{qg \rightarrow qg} \otimes ?$, involving the unpolarized parton densities and the unpolarized hard partonic subprocess. The latter because Λ polarization created in the helicity conserving hard partonic scattering is very small, $P_\Lambda \sim \alpha_s m_q / \sqrt{\hat{s}}$ [4]. The question mark indicates that at leading twist there is no collinear fragmentation function describing $q \rightarrow \Lambda^\dagger X$ for symmetry reasons. In collinear factorization P_Λ is necessarily power suppressed. Dropping the demand of *collinear* factorization, does allow for a leading twist solution: the function $D_{1T}^\perp(z, \mathbf{k}_T)$ [5] for Λ 's, depicted in Fig. 1. It describes a nonperturbative $\mathbf{k}_T \times \mathbf{S}_T$ dependence in the fragmentation process, which is allowed by the symmetries (parity and time reversal). As the Λ polarization arises in the fragmentation of an *unpolarized* quark, the descriptive name “polarizing fragmentation function” was suggested for it [6]. Currently D_{1T}^\perp is expected to be universal, despite its potential color flow dependence [7]. D_{1T}^\perp has been extracted from fixed target $p + p/Be \rightarrow \Lambda^\dagger / \bar{\Lambda}^\dagger + X$ data [6]. Reasonable functions are obtained: D_{1T}^\perp has opposite signs for u/d versus s quarks, and the latter is larger. This leads to cancellations in order that $P_\Lambda \approx 0$. This extraction has been done under the restriction of $p_T > 1$ GeV/c to exclude the soft regime, but also to retain sufficient data to make a fit to. Whether this restriction is sufficiently strict to ensure the validity of the description is a matter of concern, due to the large K factors required to obtain a cross section description.

3 Jet- Λ^\dagger production

The validity of the factorized description depends on whether a proper cross section description can be obtained. This requires data at higher \sqrt{s} and p_T , but not necessarily also at large x_F if one goes beyond $pp \rightarrow \Lambda^\dagger X$. If the origin of the transverse Λ polarization is indeed due to polarizing fragmentation, then another related asymmetry could be observed that does not need to vanish at $\eta_\Lambda = 0$, namely in the process $pp \rightarrow (\Lambda^\dagger \text{jet}) \text{jet} X$ [8]. The suggestion is to select two-jet events and to measure the jet momenta K_j and $K_{j'}$ (with $K_j \cdot K_{j'} = \mathcal{O}(\hat{s})$), in addition to the momentum K_Λ and polarization S_Λ of the Λ that is part of either of the two jets. A single spin asymmetry proportional to $\epsilon_{\mu\nu\alpha\beta} K_j^\mu K_{j'}^\nu K_\Lambda^\alpha S_\Lambda^\beta$ can then arise, which is neither power suppressed, nor needs to be zero at midrapidity. In the center of mass frame of the two jets the asymmetry is of the form:

$$\text{SSA} = \frac{d\sigma(+S_\Lambda) - d\sigma(-S_\Lambda)}{d\sigma(+S_\Lambda) + d\sigma(-S_\Lambda)} = \frac{\hat{K}_j \cdot (K_\Lambda \times S_\Lambda)}{z M_\Lambda} \frac{d\sigma_T}{d\sigma_U} \quad (1)$$

The analyzing power $d\sigma_T/d\sigma_U$ of the asymmetry depends on D_{1T}^\perp . This new Λ +jets observable could allow for a more trustworthy extraction of D_{1T}^\perp (for both quarks and gluons) and subsequent predictions, for instance for semi-inclusive DIS [9].

At LHC (and at RHIC) this process $pp \rightarrow (\Lambda^\dagger \text{jet}) X$ can be studied. For instance, ALICE with its excellent PID capabilities can measure Λ 's over a wide p_T range (for example, in a typical yearly heavy ion collision run at least up to 16 GeV/c). The ALICE rapidity coverage is $-0.9 \leq \eta \leq +0.9$. Jets can be reconstructed above 30 GeV (up to 250 GeV in a typical yearly run). If the jet rapidities $(\eta_{j,j'})$ are in this kinematic region and if gluon fragmentation is at least as important as quark fragmentation for both unpolarized and polarized Λ production, then the process is dominated by gluon-gluon ($gg \rightarrow gg$) scattering^a:

$$\frac{d\sigma_T}{d\sigma_U} \approx \frac{D_{1T}^{\perp g}(z, K_{\Lambda T}^2)}{D_1^g(z, K_{\Lambda T}^2)}. \quad (2)$$

Because no model or fit for $D_{1T}^{\perp g}$ is available yet, no predictions can be made in this case.

If it happens that $D_{1T}^{\perp g} \ll D_{1T}^{\perp q}$, then one can use the extracted $D_{1T}^{\perp q}$ to obtain an estimate. When gluons still dominate in the denominator, one finds for $\eta_{j'} \approx -\eta_j$ ($x_1 \approx x_2$)

$$\frac{d\sigma_T}{d\sigma_U} \approx [b(y) + b(1-y)] \frac{\sum_q f_1^q(x_1) D_{1T}^{\perp q}(z, K_{\Lambda T}^2)}{f_1^g(x_1) D_1^g(z, K_{\Lambda T}^2)}, \quad (3)$$

where $y = (e^{2\eta_j} + 1)^{-1}$, $x_1 \approx x_\perp / 2\sqrt{y(1-y)}$, and $b(y) = d\hat{\sigma}_{qg \rightarrow qg} / d\hat{\sigma}_{gg \rightarrow gg}$. In the considered rapidity interval the prefactor $b(y) + b(1-y)$ (≈ 0.4) is almost y independent.

In practice, it may be that D_1^g is considerably smaller than D_1^q . In that case the $qg \rightarrow qg$ subprocess needs to be taken into account in the denominator of the asymmetry too (not done

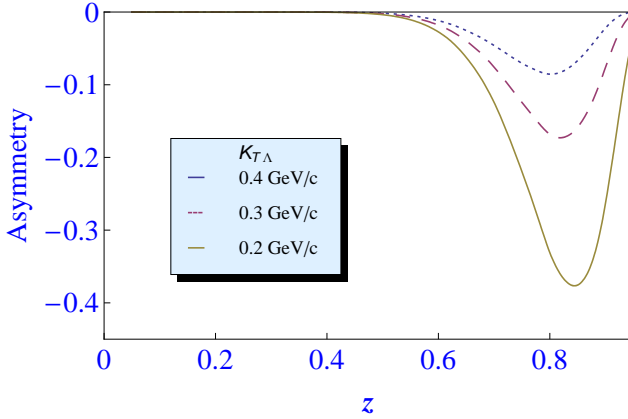


Figure 2: The asymmetry $d\sigma_T/d\sigma_U$ for $\eta_j, \eta_{j'} = 0$ and $|K_{\perp j}|, |K_{\perp j'}| = 70$ GeV, using DSV FFs.

quite sensitive to the cancellation between u/d and s contributions, like in SIDIS [9], and

^aUnlike in Ref. [8], here it will be assumed that universality of D_{1T}^\perp holds throughout. Furthermore, chiral-odd contributions [10] will not be considered here.

can even flip its overall sign depending on the amount of $SU(3)$ breaking in the unpolarized fragmentation functions (DSV assumes $SU(3)$ symmetry). More reliable estimates are not possible at this stage. ALICE would have most data in the region $z < 0.5$ and would therefore provide valuable information on gluonic contributions to D_{1T}^\perp .

4 Λ^\uparrow at forward rapidities and gluon saturation

Λ polarization is also very interesting in pA reactions at very high \sqrt{s} , large A and η . In that kinematic regime of small x , saturation of the gluon density is expected. The process $pA \rightarrow \Lambda^\uparrow X$ is sensitive to saturation and could help to determine properties of this phenomenon. None of the existing data is in the saturation regime. At high energy colliders, such as RHIC and LHC, protons often cannot be identified in the forward direction, which hampers the measurement of Λ polarization. Although relatively forward Λ 's ($y = 2.75$) in dAu collisions have been identified through event topology [12], it is not clear whether the polarization can be reconstructed in this way too, despite the self-analyzing decay property. An alternative may be to use neutral decays $\Lambda \rightarrow n\pi^0$ (50% less frequent than $p\pi^-$). Despite being a very challenging measurement, Λ polarization at forward rapidities offers a unique direct probe of gluon saturation in both pp and pPb collisions at LHC. The saturation scale Q_s and even its evolution with x could be probed in this way [13, 14].

The cross section of forward hadron production in the (near-)saturation regime is schematically of the form: pdf \otimes dipole cross section \otimes FF [15]. Since D_{1T}^\perp is \mathbf{k}_T -odd, it essentially probes the derivative of the dipole cross section. At transverse momenta of order Q_s the dipole cross section changes much, which thus leads to a Q_s -dependent peak in (strictly speaking minus) the Λ polarization. This was first demonstrated in Ref. [13] for the McLerran-Venugopalan model [16]. In this model Q_s is a constant, leading to a peak that is x_F independent. More realistically the saturation scale is expected to change with the small- x values probed: $Q_s^2(x) \propto x^{-\lambda}$. Models that incorporate this are for instance: the well-known GBW model [17], which describes well small- x DIS data; the DHJ model [18], which describes well forward $dAu \rightarrow \pi X$ RHIC data; and, the GS model [19], which describes well both types of data. In all three models $\lambda = 0.3$, as indicated by the DIS data. Here we will restrict to the latter two models. Although they have considerable differences (the GS model is geometrically scaling, the DHJ model is not; the GS model leads to more steeply falling p_T spectra of produced hadrons) [19], both the DHJ and GS models lead to the same conclusion about the peak of the Λ polarization: its x_F dependence is to very good approximation the x dependence of Q_s ! This is shown in Fig. 3 for pPb collisions at LHC (the solid line is the GS model prediction, the dashed line the DHJ one). In pp collisions at LHC Q_s and hence the \mathbf{p}_T position of the peak is slightly lower. At RHIC unfortunately the peak is likely situated below 1 GeV/c, where the formalism cannot be trusted. Therefore, Λ polarization studies at LHC could prove most interesting.

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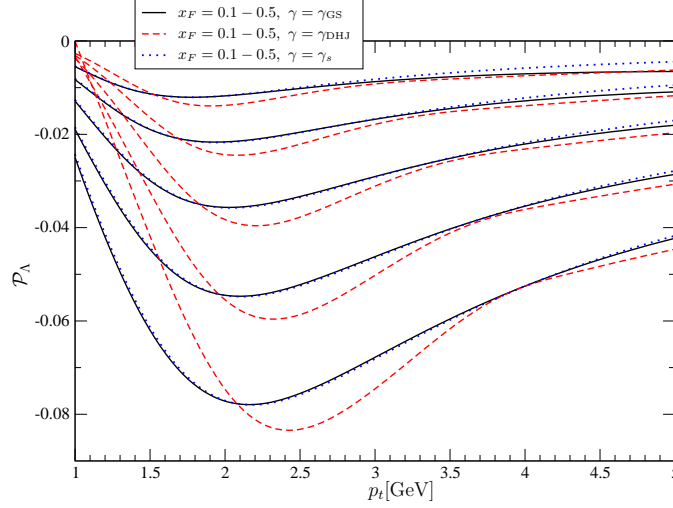


Figure 3: Predictions of Λ polarization in $p + Pb \rightarrow \Lambda^\uparrow + X$ at $\sqrt{s} = 8.8$ TeV [14].

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